Selecting a Mast Material

By Stan Griffiths, W7NI

Much has been said about the benefits of using aluminum, as opposed to steel, as a mast material to support large rotating arrays. I strongly suggest looking very carefully at the entire picture before deciding what material is right for your installation.

I recently did a comprehensive comparison between aluminum and steel for masts. My first step was to write for some sales literature from a company that advertises that aluminum is the best choice in mast materials. The following statements appeared as part of the material I received:

- "Aluminum is 1/3 the weight of steel."
- "Aluminum is 50% stronger than steel."

While these statements are not entirely false, they simply do not show the whole picture. Important conditions must be met for them to be true. For example, if you simply compare the weight of aluminum to the weight of an *equal volume* of steel, aluminum does weigh about 1/3 as much as steel. This is not a fair comparison, since *much* more aluminum is required in a mast to equal the strength of a good steel mast with the same outside diameter. We'll explore this in detail later.

Whether aluminum is stronger than steel depends on which alloys of aluminum and steel we are comparing. The company making the above statements compared 6061-T6 aluminum with typical steel water pipe, which they claim is what most hams choose for mast material. Steel water pipe is just about the *worst* choice you could make for a *steel* mast, while 6061-T6 aluminum is almost the *best* choice you could make for an *aluminum* mast. When you slant the comparison like this, you can always make aluminum look better than steel.

The most important property of metal that makes it good for a mast is its *yield strength* (the higher the better). Yield strength is a measure of the point at which a metal will permanently deform (bend) under stress. I consulted a chart of characteristics of aluminum tubing which contained 34 different combinations of alloy and temper and found aluminum yield strengths to vary from a low of 5,000 psi (pounds per square inch) to a high of 73,000 psi. Specifically, 6061-T6 has a yield strength of 40,000 psi. Only a couple of other aluminum alloys in the chart have higher yield strengths—and they're considerably more expensive than 6061-T6.

I consulted another chart with 83 different alloys and tempers of steel. The yield strengths varied from a low of 30,000 psi to a high of 250,000 psi. The steel alloy used for water pipe was not included in the chart, *which is a big clue as to its suitability for use as a mast material.* Again, I suspect the strongest alloys will cost a fortune.

I asked a steel expert what alloy he would recommend for this application. He suggested 1026 cold-drawn steel with a yield strength of 72,000 psi as a very economical choice.

So let's take this data and make a real comparison. We'll make these assumptions about our installation:

1) The length of the mast *does not* enter into the strength picture. What matters is the *bending moment* it will stand, and that's a function of yield strength, outside diameter, and wall thickness.

2) We'll assume a steel mast of alloy 1026 cold drawn, 2 inches in diameter, and a wall thickness of 0.180 inch.

3) We'll calculate the bending moment such a mast will withstand.

4) We'll then replace the mast with one made of 6061-T6 aluminum and calculate how thick the walls must be to withstand the same bending moment as the steel mast.

5) We'll compare the weight of the two masts to see which one's lighter, and by how much.

Referring to my earlier article on calculating mast strength (*NCJ*, January/February 1992), we will need to rearrange the mast stress formula to solve for the bending moment of the steel mast:

$$M = \frac{fI}{C}$$

where

M = Bending moment, in-lb

f = Yield strength, lb/in^2

I = Moment of inertia, in^4

c = Outside mast radius, in

We must first calculate I for the steel mast:

$$I = \frac{\pi (d_1^4 - d_2^4)}{64}$$

$$I = \pi(2^4 - 1.64^4) \div 64$$

$$I = \pi(16 - 7.23) \div 64$$

$$I = 0.430 \text{ in}^4$$

where

I = Moment of inertia, in^4

d_1 = Outside diameter, in

d_2 = Inside diameter, in

Next, we'll calculate the bending moment the steel mast will stand:

$$M = (72{,}000)(0.430) \div 1$$

$$M = 30{,}960 \text{ in-lb}$$

Working backward from here, we can calculate the required moment of inertia that an aluminum mast must have to withstand the same bending moment as we just calculated for our steel mast:

$$I = \frac{Mc}{f}$$

$$I = (30{,}960)(1) \div 40{,}000$$

$$I = 0.774 \text{ in}^4$$

Rearranging the moment of inertia formula to solve for d (inside diameter), we have:

$$d_2 = \sqrt[4]{16 - (64)(0.774) \div 3.14}$$

$$d_2 = 0.7 \text{ in}$$

Yes, this means that, to have a yield strength equal to a 1026 steel mast, a 2-inch OD 6061-T6 aluminum mast must have a wall thickness of *0.65 inches.* In other words, it must resemble a *solid rod two inches in diameter with a 0.7 inch hole down the center!*

Next, we'll compare the weights of these equally strong masts. Remember that for a given volume of material, steel weighs three times as much as aluminum. Also, the volume of a cylinder is directly proportional to its cross-sectional area. The cross-sectional area of a cylindrical tube is determined by calculating the difference between the area of a circle with a diameter equal to the outside diameter of the tube and subtracting the area of a circle with a diameter equal to the inside diameter of the tube. A comparison of the cross-sectional areas of the two masts will allow us to compare their weights, assuming their lengths are equal.

Since both masts have the same outside diameter, we'll calculate the area of the outside circle first:

$$A = \pi r^2$$

$$A = (3.14)(1^2) = 3.14 \text{ in}^2$$

where r = outside radius, in

Next we'll calculate the area of the inside circle of the steel mast:

$A = \pi r^2$

$A = (3.14)(0.82^2)$

$A = 2.11 \text{ in}^2$

where r = inside radius, in

Subtracting the inside area from the outside area gives a total cross-sectional area for the steel mast:

$A = 3.14 - 2.11 = 1.03 \text{ in}^2$

Next we'll calculate the area of the inside circle of the aluminum mast:

$A = \pi r^2$

$A = (3.14)(0.35^2) = 0.38 \text{ in}^2$

where r = inside radius, in

Subtracting the inside area from the outside area gives a total cross-sectional area for the aluminum mast:

$A = 3.14 - 0.38 = 2.76 \text{ in}^2$

Note that the cross-sectional area of the aluminum mast is *nearly three times that of the steel mast*, which means that it contains three times the volume of material as the steel mast and *it will therefore weigh nearly the same amount as the steel mast!*

As near as I can tell, there are only two ways to increase the strength of the aluminum mast:

1) Go for a stronger alloy. The cost will probably rule this out.

2) Increase the *outside* diameter, since you're already beyond the practical limit for increasing wall thickness. You probably already know the implications of going larger than 2 inches outside diameter for a mast: You can't use standard 2-inch thrust bearings; you can't use standard tower top sections made to fit 2-inch masts; you'll have fun trying to fit a larger mast into a standard 2-inch rotator; and your antenna boom-to-mast mounting hardware probably won't fit the larger mast.

There is another solution: *use a steel mast.* You have the option of increasing the wall thickness quite a lot. Going from just 0.18-inch wall to 0.2-inch wall in a good steel mast increases the mast's strength well beyond that of a *solid* 2-inch aluminum rod! Imagine the strength you'll get if you go to 0.25-inch wall steel! No, don't imagine it. Calculate it. You have all the knowledge to do it right now.

In fairness to the advocates of aluminum masts, I am well aware that filling in the center of a tube with more material is not the best way to increase its bending moment. As you can see from the above example, the weight goes up much faster than the strength. So, let's work through one more example:

This time, we'll choose a 2-inch outside diameter 6061-T6 aluminum mast with 0.25-inch wall and calculate the bending moment it will stand.

Next, we'll calculate the required wall thickness for a 2-inch OD 1026 cold-drawn steel mast required to withstand the same bending moment.

Then, we'll compare weights by comparing cross-sectional areas as we did in the first example.

The first step is to determine the moment of inertia for the aluminum mast:

$$I = \frac{\pi (d_1^4 - d_2^4)}{64}$$

$I = (2^4 - 1.5^4) \div 64$

$I = (16 - 5.06) \div 64$

$I = 0.537 \text{ in}^4$

where

I = moment of inertia, in^4

d_1 = outside diameter, in

d_2 = inside diameter, in

Next, we'll find the bending moment the aluminum mast will stand:

$$M = \frac{fI}{C}$$

$M = (40{,}000)(0.537) \div 1$

$M = 21{,}480 \text{ in-lb}$

where

M = bending moment, in-lb

f = yield strength, lb/in^2

I = moment of inertia, in^4

c = outside mast radius, in

Working backward from here, we can calculate the required moment of inertia that a steel mast must have to withstand the same bending moment as we just calculated for our aluminum mast:

$I = (M)(c) \div f$

$I = (21{,}480)(1) \div 72{,}000$

$I = 0.298 \text{ in}^4$

Rearranging the moment-of-inertia formula to solve for d (inside diameter), we have:

$$d_2 = \sqrt[4]{16 - (64)(0.298) \div 3.14}$$

$d_2 = 1.78$ in

Subtracting the inside diameter from the outside diameter and dividing the result by 2 gives a wall thickness of 0.110 inch.

We'll compare weights the same way as in the first example. The outside area of both masts is 3.14 in^2 and the inside area of the aluminum mast is:

A = r

$A = \pi(0.75)^2$

$A = 1.77 \text{ in}^2$

This gives the aluminum mast's cross-sectional area:

$A = 3.14 - 1.77 = 1.37 \text{ in}^2$

Now, calculating the inside area of the steel mast:

$A = \pi(0.89)^2$

$A = 2.49 \text{ in}^2$

The steel mast's cross-sectional area is:

$A = 3.14 - 2.49 = 0.65 \text{ in}^2$

You can see that the aluminum mast in this example still has more than twice the cross-sectional area as the steel mast and therefore will weigh approximately ⅔ as much. Granted, it's lighter, but it's not a third of the weight of a *good* steel mast, as has been suggested by others.

So how does aluminum stack up against steel for price? Well, I did a little checking with some local sources and here are some comparisons (shipping is not included):

- A 24-foot length of 6061-T6, 2 inches outside diameter, 0.25-inch wall aluminum tubing is $212.94.
- The equal-strength 1026 cold-drawn steel tubing has a wall thickness of 0.11 inch. It comes in 0.109-inch wall (very close) and costs $68.16 for a 24-foot length. If you want a stronger variety, you can get the 0.12-inch wall version for $74.88 (24-foot length).
- If you want to try using an aluminum alloy that is stronger than 6061-T6, I priced 7075-T6, 2-inch outside diameter, 0.25-inch wall, 24 feet long, at $660.60. The problem here is that my supplier can only get it in 12-foot lengths, which would be half price, or $330.30. This is an aluminum alloy that truly *is* as strong as good steel (73,000-psi yield strength).

The equal-strength 1026 cold-drawn, 2-inch OD steel tubing would also have a 0.25-inch wall. A 24-foot piece costs $157.68.

If you are still convinced you want to use aluminum, you can always go to the solid 2-inch 6061-T6 rod, which costs $253.44 if you can get a 24-foot piece. My

supplier can only get it in 12-foot pieces ($126.72).

I also looked at stainless steel as an alternative. Most stainless-steel alloys have yield strengths of 30,000 to 45,000 psi, which isn't any better than 6061-T6 aluminum. Hard-drawn stainless steel is usually in the 75,000-psi range but is difficult to find. My supplier asked me how many tons I wanted and when I said one piece, after he was through laughing, he said it would certainly cost me more than $1000, since it would be a special order.

One disadvantage of steel is that you'll have to protect it from rusting. Some people go to the trouble of having their steel masts galvanized. If you want to do that, it costs $0.255 per pound, with a $45 minimum, when Tom Hill, WA3RMX, had such a mast galvanized in 1991.

I paint steel masts with rust-inhibiting paint, which works very well. Steel tubing usually comes covered with a protective grease that must be thoroughly cleaned off before painting. Ordinary paint thinner is a good solvent to use for this. With a little ingenuity, you can figure out how to clean and paint the inside of the tubing also. I have had two steel masts in place here in rainy Oregon for 20 years and they are only rusty where I accidentally scratched the paint during installation.

Since it is relatively easy to weld steel, you can consider building a tapered mast with a larger outside diameter where maximum strength is required and a smaller size where it isn't. It's not so easy to weld aluminum. If you consider splicing masts by drilling holes and bolting them together, you will have to consider how much the missing bolt-hole material will weaken the mast. That calculation is beyond the scope of this or my previous paper on mast design, but it's covered in the Technical Correspondence column in October 1992 *QST*. You may need to hire a consulting engineer.

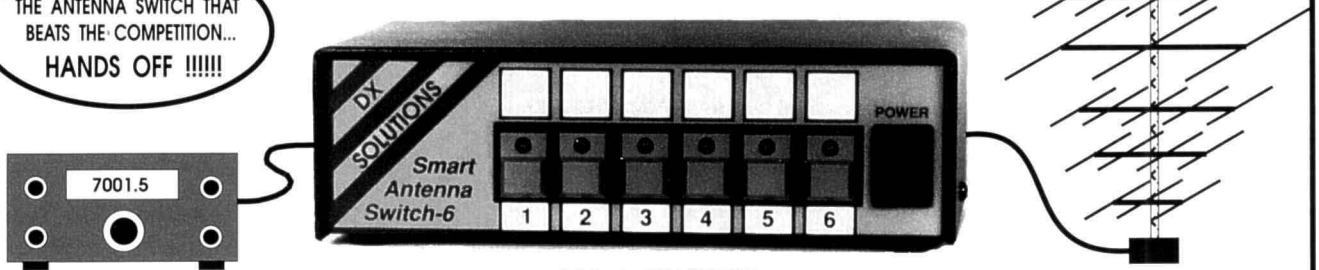
There is *no way* I'll ever use an aluminum mast for any heavy work at W7NI. And, by the way, I don't use water pipe either! I even get nervous using an aluminum gin pole.

WHY NOT HAVE THE **ULTIMATE** CONTEST STATION?

DX SOLUTIONS presents the

Smart Antenna Switch

THE ANTENNA SWITCH THAT BEATS THE COMPETITION... HANDS OFF !!!!!!



TRANSCEIVERS

KENWOOD: TS-950, TS-850, TS-450, TS-690, TS-940*, TS-680*, TS-440*, TS-140*,...

ICOM: IC-781, IC-765, IC-761, IC-735, IC-728, IC-726, IC-725, IC-751A*,...

YAESU: FT-1000, FT-990, FT-767,FT890

TEN-TEC: OMNI-VI, DELTA II, ARGONAUT II

*These radios require additional manufacturer's hardware. Call DX SOLUTIONS for details.

As a replacement for an existing remote coax switch, the SAS-6 is compatible with the following relay units:

DX Engineering **Ameritron**
Heathkit **Custom Units**

SAS-6 FEATURES

- Automatic antenna switching based on the frequency band of operation
- Compatible with newer KENWOOD, ICOM, Yaesu, and TEN-TEC transceivers
- Selects from up to six (6) different antennas
- Easily programmable from the front panel
- Manual override modes
- Supports monoband or multiple band antennas per switch
- LEXAN© front panel for easy labeling of antennas
- No software required
- No extra COM port required
- Can replace the manual switching unit of most remote coax switches

Great for guest ops....Never transmit on the wrong antenna again !!

Allows instant QSY to grab needed multipliers !!

No fumbling with rotary switches in the manual mode. Simply touch and go !!

SAS-6 Retail Price $299.95

SAS-6 + DX Engineering's 6-position outdoor relay unit - $419.95

U.S. postpaid. (AL residents add 5 1/2%)

Computer control interface (such as DX SOLUTIONS' CT-232) required with Kenwood, Icom, and some Ten-Tec radios.

DX SOLUTIONS
147 SOUTH VIEW DR.
HUNTSVILLE, AL 35806
(205) 922-1724